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LASER EYE PROTECTION FOR FLIGHT PERSONNEL

VOLUME I

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Developments in laser technology have resulted in an expanding use of lasers in many fields and laboratory situations. The implications of the use of lasers in military applications have been examined for flight personnel, and the requirement for eye protection determined. Recommendations for methods of providing that protection are made.

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INTRODUCTION

The term Laser is an acronym derived from Light Amplification by Stimulated Emission of Radiation. The effects of laser radiation are essentially the same as light generated by more conventional sources. The unique biological implications attributed to laser radiation are those resulting from the very high intensities and monochromaticity of laser light. Such sources differ from conventional light emitters primarily in their ability to attain highly coherent light. The increased directional intensity of the light generated by a laser results in concentrated light beam intensities at considerable distances. Recent developments in laser technology have resulted in an increase in the utilization of these devices for military applications, both in research and field use. The increased use of these systems increases the probability of exposure of personnel to injurious effects of the laser radiation. Safeguards must be provided to protect personnel from these potentially hazardous effects.

To identify the potential hazard of a laser, lasers have been classed into four categories (1). A class I laser is one which is considered to be incapable of producing radiation damage under any conditions, therefore, no control measures are required. A class II laser is a low powered laser which may be viewed directly under controlled exposure conditions but must have a cautionary label attached to the external surfaces of the device. A class III laser or, a medium power laser, requires control measures to prevent viewing of the direct beam. The class IV laser is a high powered laser and requires controls and precautionary techniques to prevent damage to personnel. To assess the hazard posed by a laser, it is necessary to determine the output of the laser and compare that output with the maximum permissible exposure (MPE) levels which have been established by using experimental laser effects data to arrive at MPE conventions, determine the distances at which MPE levels will be reached, and determine the extent of protection required to reduce the exposure levels to the MPE for personnel who must operate inside the safe separation distances.

HAZARD ANALYSIS

The analyses in this paper will be limited to the class IV high powered lasers in the visible and the near infrared region, the visible wavelengths being 400 to 700 nanometers (nm) and the near infrared region being 700 to 1400 nm. The characteristics of lasers in this wavelength range which are classified as class IV lasers are an average accessible radiant power of 1/2 watt or greater, for periods greater than 0.25 seconds; or a radiant exposure in excess of 31 millijoules per square centimeter in nanosecond pulses or that required to produce a hazardous diffuse reflection for periods less than 0.25 seconds. The hazards from laser exposures may be both skin burn hazards and eye damage hazards. The analyses of this paper are limited to the eye hazards.

The environment in which the lasers in this evaluation are assumed to be operating is an outdoor, free field environment. The range of laser intensities, pulse durations, and pulse repetition frequencies have been selected to cover those with potential military use as tactical systems. The wavelength selected is 1060 nm. The exposures considered are intrabeam exposures, those in which the apparent visual angle subtended is less than α_{min} as defined by the American

National Standard Z136.1 1976, "Standard for the Safe Use of Lasers", the duration range is 50 microseconds (μs) to 1 nanosecond (ns), the emergent beam diameter range is 3 to 5 centimeters (cm), the beam divergence range is 3.9×10^{-4} to 7.5×10^{-4} radians, the pulse repetition frequency range is 1 to 200 Hertz (Hz) and the energy output range is 100 to 150 millijoules (mJ).

The energies per pulse at the eye of eight lasers of various combinations of characteristics at distances from zero to 20 kilometers (km) are shown in figure 1. The characteristics of the lasers are shown in table I. The MPEs for lasers in this range for pulse repetition frequencies (PRF) from 1 to 200 Hz are shown in figure 2. It is possible then to select a pulse repetition frequency, find the MPE from figure 2, and then determine the safe exposure distance for the lasers plotted in figure 1. The values in figure 1 cover a range which will permit extrapolation to a variety of specific lasers. Equation 1 has been used to calculate the energy at the eye shown in figure 1.

$$H = \frac{1.27\ Qe^{-\mu r}}{(a+r\phi)^2} \tag{1}$$

where H = exposure at the eye

Q = energy output per pulse in Joules

μ = atmospheric attenuation coefficient per cm at a specific wavelength

r = distance between the viewer and the laser output port in centimeters

a = diameter of the emergent beam at the 1/e point in centimeters

ϕ = emergent beam divergence in radians

PROTECTIVE DEVICES

It was determined from the analyses above that eye protection for personnel operating within the safe exposure distances for lasers of the type plotted in figure 1 is necessary. Several types of eye protection have been examined. A visor lens, which provides adequate absorption for the wavelength in question, is considered most suitable for flight personnel.

The types of eye protection which are available for application to the problem of eye protection for flight personnel are laboratory goggles and spectacles, standard aviator's spectacles with special lenses and helmet visor lenses. The laboratory goggles and spectacles are suitable for laboratory use but for several reasons are not suitable for a flight environment. The goggles have soft frames which conform to the face and a flat plate filter to provide the required filter characteristics. The laboratory spectacles are plastic frame spectacles with plano lenses and opaque side shields. The spectacle and goggle configurations are shown in figure 3. The optical densities (o.d.) of the goggles and spectacles range from 5 to 22 with luminous transmittance of 35 to 46 percent. The bulk, peripheral vision loss, and luminous transmittance

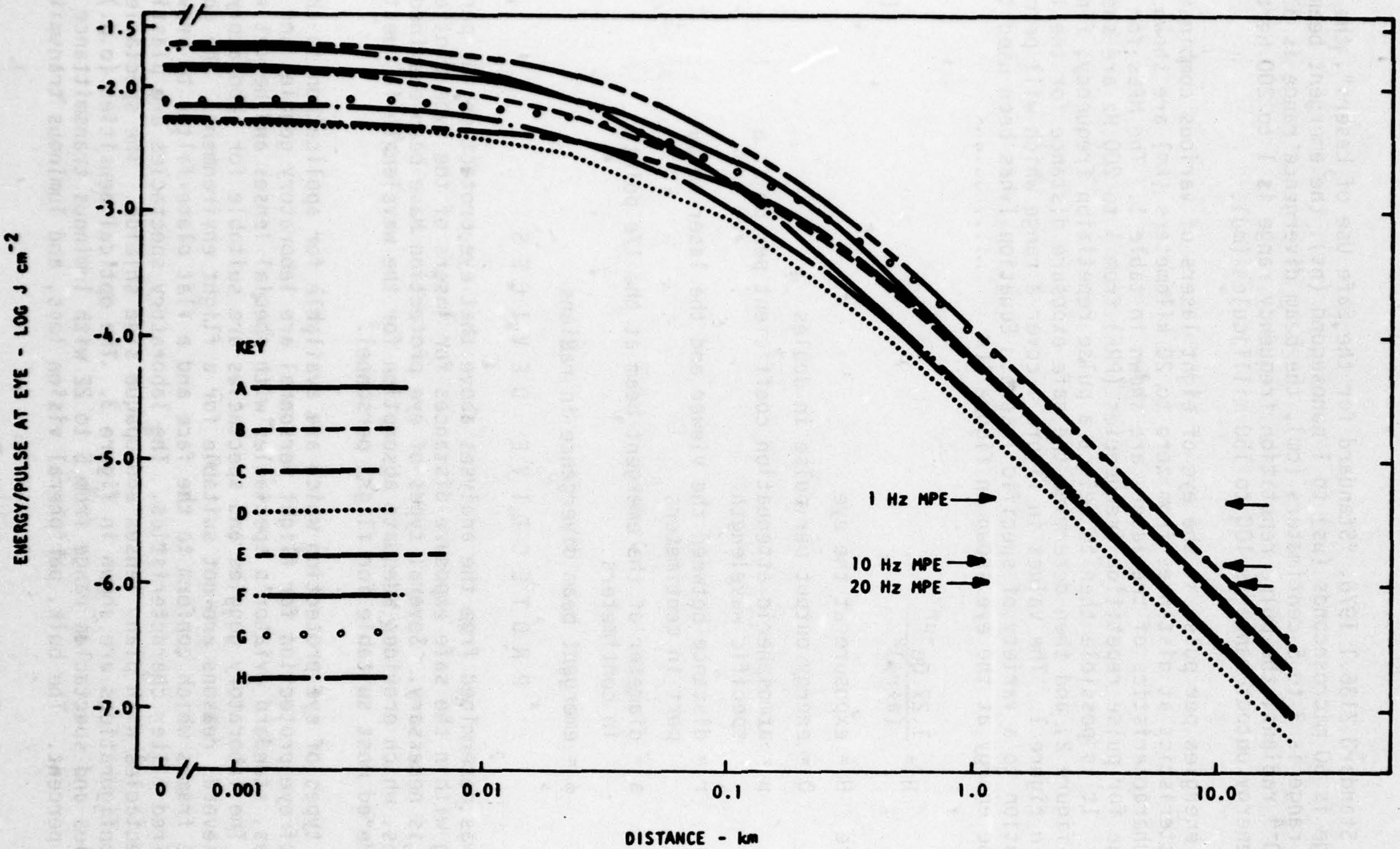

FIGURE 1 - Energy per pulse at eye for near IR (λ = 1.06 - 1.400 μm) lasers from 100 millijoules/pulse, 1×10^{-9} second pulse duration, 1 Hertz; output beam diameter 5 centimeters, beam divergence 0.75 milliradians to 150 millijoules/pulse, 1x10-7 second pulse duration, 1 Hertz; output beam diameter 3 centimeters, beam divergence 0.39 milliradians.

TABLE I

COMBINATIONS OF LASER CHARACTERISTICS

Laser	Output Energy - Millijoules	Output Beam Diameter - Cm	Beam Divergence - Milliradians
A	100	3	0.39
B	100	3	0.75
C	100	5	0.39
D	100	5	0.75
E	150	3	0.39
F	150	3	0.75
G	150	5	0.39
H	150	5	0.75

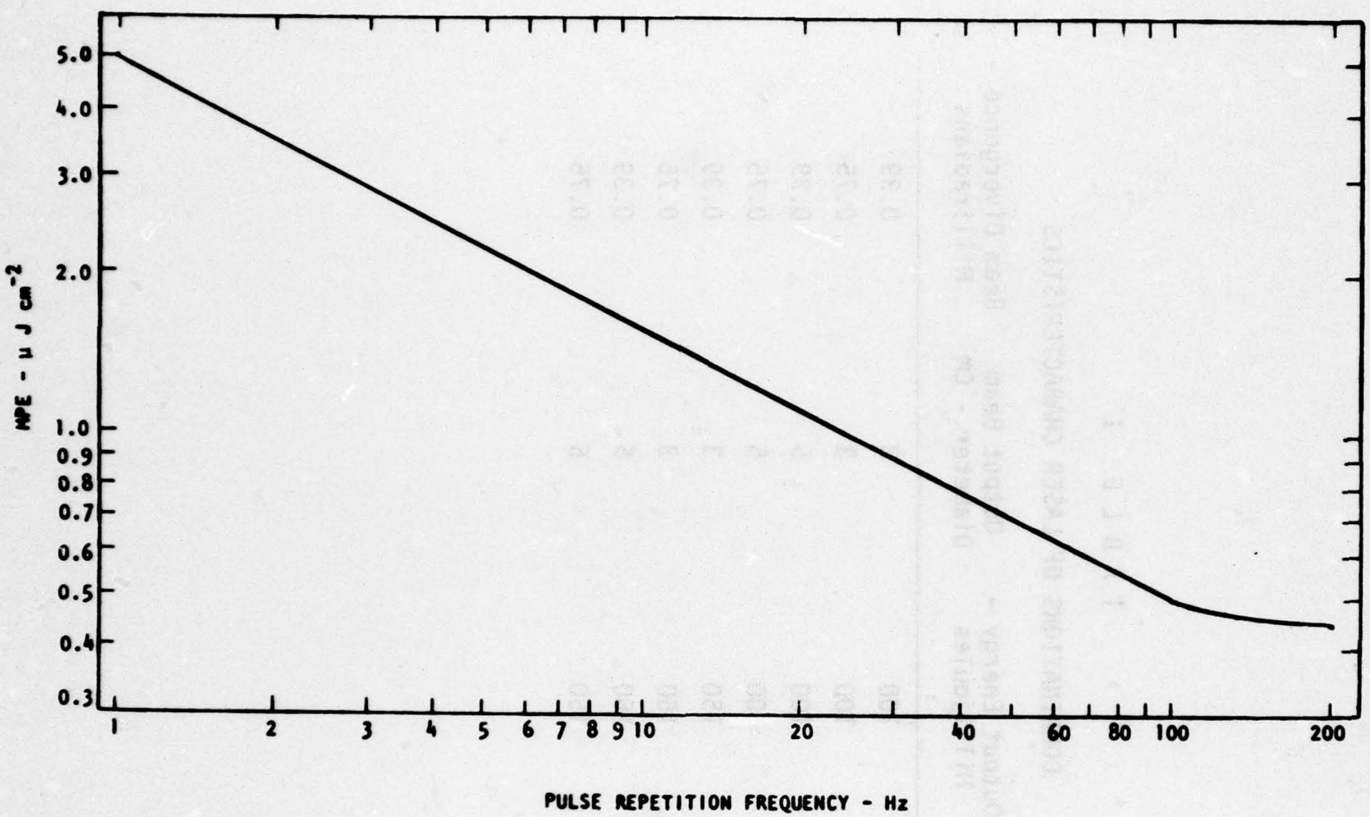

FIGURE 2 - MPEs for near IR lasers, pulse duration 1×10^{-9} to 5×10^{-5} second, pulse repetition frequencies 1 to 200 Hertz.

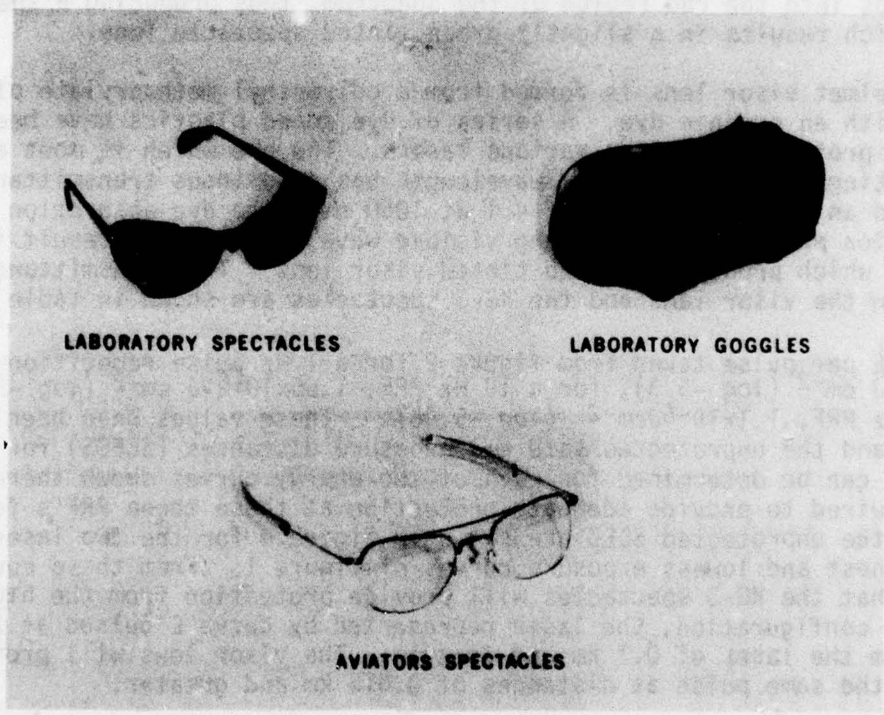

FIGURE 3 - Laboratory goggles and spectacles.

are features which make the use of these types of protection devices unsuitable for flight personnel. They are suitable for shop or ground crew use.

The special lenses in standard aviator's spectacle frames have been proposed and are undergoing evaluation as protective devices for flight personnel protection. The lenses are tempered glass, and therefore are less hazardous than standard glass lenses, however they do not provide high impact protection. The lenses of a desired density can be ground for either plano or prescription characteristics. The spectacle configuration which has been proposed is a 3 millimeter thick KG-3 tempered glass with a visible transmittance of 80 percent and an o.d. of 3.6 at 1060 nm. The spectacles weigh 42.22 grams (1.49 oz.) which is slightly, though not significantly, heavier than the standard aviator's sunglasses which weigh 38.9 grams (1.37 oz.). The KG-3 glass absorption extends into the red region of the spectrum, thus producing a spectral distortion which results in a slightly green tinted spectacle lens.

The helmet visor lens is formed from a polymethyl methacrylate plastic which is doped with an organic dye. A series of dye doped plastics have been developed for use in protecting against various lasers. The one which is most appropriate for protecting against a 1060 nm wavelength has a luminous transmittance of 70 percent and an optical density of 4.1 at 1060 nm. The dye absorption in this configuration extends into the long visible wavelengths. The result is a spectral distortion which produces a green tinted visor lens. The transmittance characteristics of the visor lens and the KG-3 spectacles are shown in table II.

The MPE per pulse taken from figure 2 for a 1 Hz pulse repetition frequency (PRF) is 5×10^{-6} J cm^{-2} (log -5.3), for a 10 Hz PRF, 1.55×10^{-6} J cm^{-2} (log -5.81) and for a 20 Hz PRF, 1.1×10^{-6}Jcm^{-2} (log -5.96). These values have been marked on figure 1, and the unprotected safe eye exposure distances (SEEDS) for each of these PRFs can be determined for each of the energy curves shown there. The densities required to provide adequate protection at these three PRF's for distances less than the unprotected SEED are shown in figure 4 for the two lasers represented by the highest and lowest exposure curves of figure 1. From these curves, it is apparent that the KG-3 spectacles will provide protection from the highest exposure laser configuration, the laser represented by curve E pulsed at 20 Hz, at distances from the laser of 0.1 km and greater. The visor lens will provide protection from the same pulse at distances of 0.015 km and greater.

DISCUSSION

The determination of the required protection and the preferred method of providing that protection should be made on the basis of the foregoing type of analysis and operational considerations. The calculations reported here indicate that in any circumstance in which the path from these lasers to a viewer, either direct or via a specular reflector, is 10 km or less, eye protection should be provided. If there is a reasonable probability that the path will be no less than 0.1 km, a protective device with a density of 3.6 at 1060 nm will be adequate. If the assumption is that the path will be less than 0.1 km, higher density will be required. Another operational consideration which will influence the decision as to the type of protection to be utilized is compatibility with other protective equipment and personal preference. Eye protection has typically been provided for high performance aircraft flight personnel by means of a helmet visor lens. The visor lens provides both protection from mechanical hazards such as bird strikes, foreign

TABLE II

SPECTACLE AND VISOR CHARACTERISTICS

	Luminance Transmittance	Optical Density at 1060 nm	Lens Color
K-3 Spectacle	80%	3.6	Slight Green
Visor Lens	70%	4.1	Light Green

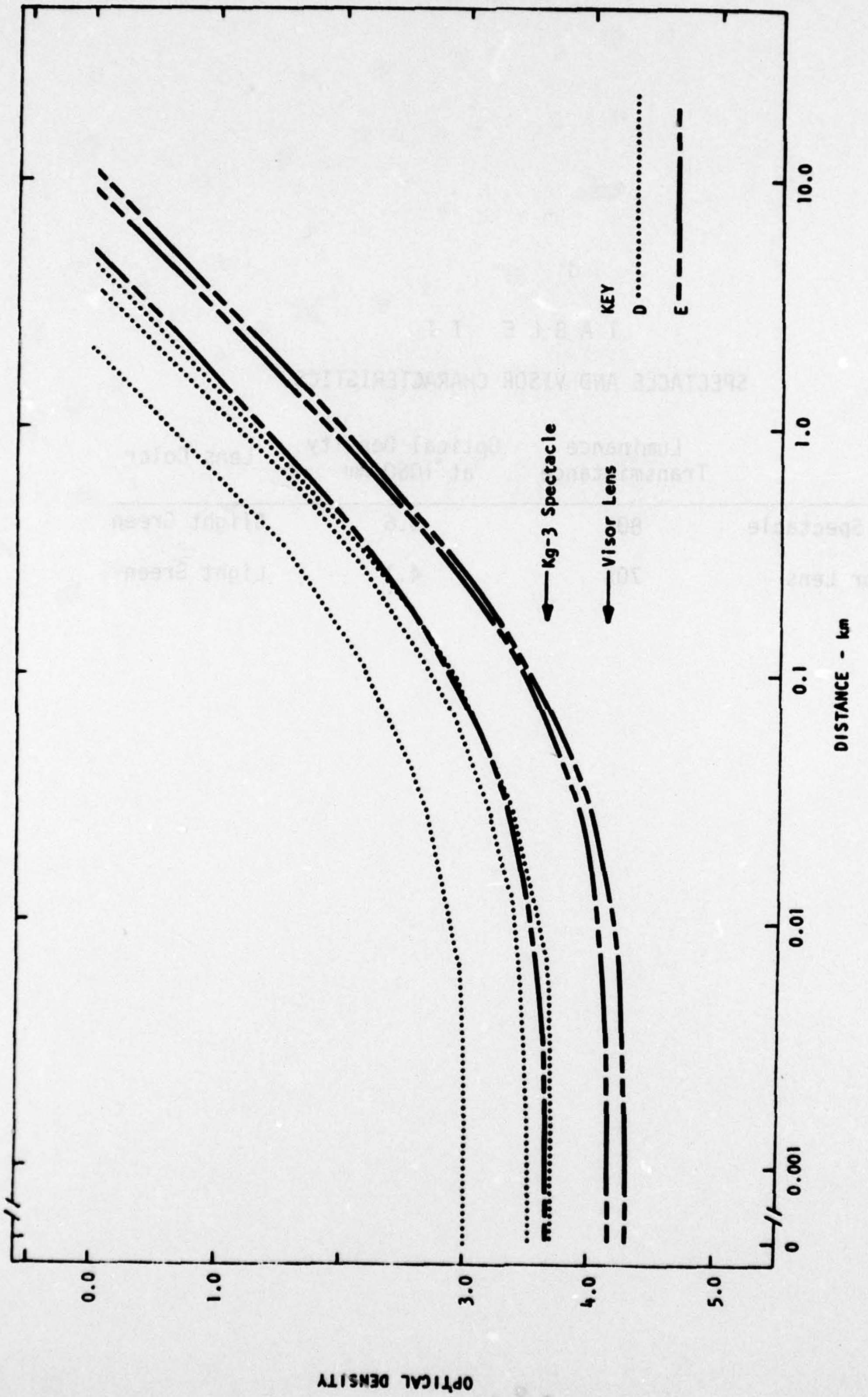

FIGURE 4 - Densities required for eye protection at various distances from a near IR laser.

bodies inside the cockpit, wind damage during ejection, and from excessive light exposure. During low-light level conditions, only the former protection is necessary, and a clear visor lens is required. During high-light level conditions, both types of protection are necessary and a tinted visor lens is used. To satisfy the requirements of both situations, a dual visor which includes a clear and a tinted visor lens has been used. An alternative which has been preferred by some flight personnel is to use a clear visor in all circumstances and to wear tinted spectacles in high-light conditions. The spectacle alternative compromises sound attentuation needed for ear protection and communication enhancement (2), and, in the case of formfit helmets, some comfort. In addition, the spectacles may be difficult to remove or don in flight. The solution to the problem of laser protection is similar but a bit more complicated. A visor must be worn for mechanical protection. Laser protection may be required in both day and night conditions, and in the day, high-light protection will be necessary. The solution which seems the least encumbering is a dual visor in which a laser protective lens and a tinted lens are used. Whenever an aircraft is in a laser environment, the laser lens is used. Whenever there is a high-light environment, the tinted lens is used. When necessary, both are used. If the spectacle alternative is chosen, the clear visor lens may be selected for the visor. At night the spectacles and the clear visor can be used in a laser environment. During the day a laser environment would necessitate a different helmet, or a change of visor to provide both laser and sun protection since two pairs of spectacles could not be used. For a mission which started at night and extended into the day, either sun protection or laser protection must be sacrificed, two helmets must be carried or a dual visor must be used along with the spectacles. On the basis of these types of considerations, a helmet configured with a dual visor in which a laser lens and a tinted lens are used is recommended for head/eye protection in a laser environment.

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